

Impact of Recent Increase in Incidence on Future Diabetes Burden

U.S., 2005–2050

K.M. VENKAT NARAYAN, MD
JAMES P. BOYLE, PHD
LINDA S. GEISS, MA

JINAN B. SAADDINE, MD
THEODORE J. THOMPSON, MS

In an earlier study, we had forecasted 39 million with diagnosed diabetes in 2050 in the U.S. (1,2). However, since then, national diabetes incidence increased (3) and the relative risk of death among people with diabetes declined (4,5). These changes will impact future forecasts.

Incorporating these changes, we now project 48.3 million people with diagnosed diabetes in the U.S. in 2050. We also present age-, sex-, and race/ethnicity-specific forecasts, with Bayesian CIs, of the number of people with diagnosed diabetes through 2050.

RESEARCH DESIGN AND METHODS

We used a discrete-time (1-year intervals), incidence-based Markov model with three states (no diagnosed diabetes, diagnosed diabetes, and death) (1). In each cycle of the model, projections are developed for 808 population subgroups defined by age, sex, and race/ethnicity.

We estimated the age-, sex-, and race/ethnicity-specific prevalence and incidence of diabetes from the U.S. National Health Interview Survey (6–9) and modeled data for 1984–2004 to improve the precision of 2004 estimates.

Models were fit using Bayesian methods with improper flat priors applied to logistic regression. We assessed adequacy of model fit using posterior predictive P values (10). Estimated prevalence of diagnosed diabetes for 2000 and 2004 were

4.35 and 5.37%, respectively, and estimated incidence were 0.42 and 0.53% per year, respectively. The age-, sex-, and race/ethnicity-specific 2004 prevalence estimates were combined with U.S. population data for 2004 (11) to determine the initial distribution of individuals across disease states. Additionally, census projections of U.S. live births, mortality rates, and net migration were required (11).

Estimates of the relative risk of mortality for people with diabetes were drawn from updates of a published study using Bayesian methods applied to logistic regression models (5). These estimates were sex- and age-group-specific for adults (aged ≥ 18 years) in four age categories.

Probabilities of remaining in the no-diabetes and diabetes states vary over time, since mortality rates are time varying. The 1-year probability of remaining with no diabetes equals $(1 - P_{ND-D} - P_{t,ND-Death})$, where P_{ND-D} is the time-independent incidence rate to diagnosed diabetes and $P_{t,ND-Death}$ equals the time-varying no-diabetes mortality rate.

We derived posterior distributions of all unknown parameters (age-, sex-, race/ethnicity-specific prevalence and incidence and age- and sex-specific relative risk) and propagated the uncertainty in these distributions through the Markov projection model. In fitting the models, we obtain 5,000 samples from the posterior distributions. The projection model is then run and results saved using each of

these 5,000 samples. This gives a sample from the posterior distribution of the projection results. Means of these posterior distributions are our estimates, and quantiles (0.025, 0.975) of these posterior distributions are our CIs.

RESULTS— Total prevalence more than doubles from 2005 to 2050 (from 5.62 to 12.00%), and all age-specific prevalence are expected to rise steadily (Table 1). Increases in the number of individuals with diabetes are projected for both sexes (men by 174%: from 7.59 million in 2005 to 20.81 million in 2050; and women by 220%: from 8.59 million to 27.47 million, respectively) and for all age-groups. These increases are largest for the two oldest age-groups: 220% among those aged 65–74 years and 449% among those aged ≥ 75 years. The number of women aged ≥ 75 years with diabetes will rise 470% (from 1.72 to 9.80 million), and the number of men aged ≥ 75 years will rise 423% (from 1.15 to 6.01 million).

Diabetes prevalence is projected to increase by 99% among non-Hispanic whites (from 5.35 to 10.64%), by 107% among non-Hispanic blacks (from 7.39 to 15.29%), by 127% among Hispanics (from 5.47 to 12.39%), and by 158% among other races (from 5.42 to 14.01%). Increases in the number of individuals with diabetes will be largest for minority groups; between 2005 and 2050, the number is projected to increase 481% among Hispanics, 208% among blacks, and 113% among whites. The age-race/ethnicity group with the largest increase will be for blacks aged ≥ 75 years (increased 606%).

CONCLUSIONS— We project that the number of individuals with diagnosed diabetes in the U.S. will increase by 198% from 16.2 million in 2005 to 48.3 million in 2050. This projection for 2050 is 9.3 million people higher than our earlier estimate (1). Eighty-seven percent of the additional 9.3 million is explained by the increase in national diabetes incidence between 2000 and 2004 (3) and 11% by

From the Division of Diabetes Translation, Centers for Disease Control and Prevention, Atlanta, Georgia.

Address correspondence and reprint requests to K.M. Venkat Narayan, MD, Division of Diabetes Translation, Centers for Disease Control and Prevention, 4770 Buford Hwy., NE, MS K-10, Atlanta, GA 30341-3717. E-mail: kav4@cdc.gov.

Received for publication 2 June 2006 and accepted 3 June 2006.

The views and conclusions expressed in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

DOI: 10.2337/dc06-1136

© 2006 by the American Diabetes Association.

The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked "advertisement" in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

Table 1—Forecasts of the prevalence and number of people with diagnosed diabetes by age-group and selected years

	Age-group (in years)					All ages
	0–19	20–44	45–64	65–74	≥75	
2005						
Prevalence (%)	0.33	2.39	10.12	18.34	15.99	5.62
<i>n</i> *	0.26	2.38	7.26	3.40	2.88	16.18
95% CI	(0.22–0.30)	(2.27–2.49)	(6.98–7.53)	(3.28–3.52)	(2.74–3.02)	(15.59–16.75)
2010						
Prevalence (%)	0.41	2.91	11.60	20.68	18.93	6.84
<i>n</i> *	0.33	2.90	9.30	4.38	3.62	20.52
95% CI	(0.25–0.41)	(2.72–3.08)	(8.90–9.70)	(4.20–4.56)	(3.38–3.86)	(19.75–21.32)
2020						
Prevalence (%)	0.46	3.59	14.52	23.32	24.20	8.88
<i>n</i> *	0.38	3.77	11.77	7.31	5.60	28.84
95% CI	(0.25–0.55)	(3.43–4.13)	(11.05–12.48)	(6.90–7.73)	(5.16–6.05)	(27.35–30.38)
2030						
Prevalence (%)	0.47	4.00	15.90	25.96	27.69	10.38
<i>n</i> *	0.42	4.41	12.40	9.82	9.35	36.41
95% CI	(0.27–0.61)	(3.96–4.92)	(11.57–13.21)	(9.20–10.44)	(8.63–10.08)	(34.23–38.63)
2040						
Prevalence (%)	0.47	4.07	16.72	28.70	30.32	11.35
<i>n</i> *	0.46	4.69	14.27	9.63	13.71	42.76
95% CI	(0.30–0.66)	(4.16–5.29)	(13.30–15.25)	(9.03–10.24)	(12.61–14.83)	(40.02–45.54)
2050						
Prevalence (%)	0.48	4.18	17.76	30.10	32.69	12.00
<i>n</i> *	0.50	5.19	15.90	10.88	15.81	48.28
95% CI	(0.32–0.73)	(4.59–5.87)	(14.79–17.00)	(10.22–11.58)	(14.47–17.17)	(45.05–51.53)
% change 2005–2050						
Prevalence (%)	45	75	75	64	104	114
<i>n</i> *	92	118	119	220	449	198

*Forecast of the number of individuals diagnosed with diabetes (in millions).

the recent decline in relative risk of mortality among individuals with diabetes (4,5). Other local and regional studies confirm increases in diabetes incidence (12–14), and the reductions in relative risk of mortality may reflect decreases in risk factors and improved diabetes quality of care (15–17).

Our projections have limitations. We assume constant 2004 diabetes, but this may be unlikely as obesity prevalence continues to increase (18). We also assume no advances in prevention, no possibility of a cure, no increases in life expectancy, no increases in screening, or no changes in diagnostic criteria. Diabetes was determined by self-report, but the validity of self-report is high (19). As we cannot distinguish diabetes types, our projections largely reflect type 2 diabetes, the predominant form of diabetes (20). We assume the middle series of the census projections, but these population projections for racial/ethnic minority groups may be underestimates.

Our projections, however, have par-

ticular strengths. The model is based on incidence and uses nationally representative age-, sex-, and race/ethnicity-specific data on incidence. The assumptions about relative risks were robust in sensitivity analysis. The Bayesian CIs account for uncertainty in model transition rates, including incidence, and provide an easily interpretable range for the projections. While we project 48.3 million individuals with diagnosed diabetes in 2050, we are 95% certain that this estimate will fall between 45 and 51.5 million.

Our revised projection (assuming constant 2004 national incidence rates) of the future national diabetes burden appears more alarming than previously estimated (1). For a chronic disease, such as diabetes, small shifts in incidence have large implications for future prevalence of and numbers with the disease. If incidence rates continue to rise, the impact on future numbers with diabetes, and consequent health care costs, will be much more devastating. Implementation of ev-

idence-based primary prevention (21) is thus an urgent national priority.

References

1. Honeycutt AA, Boyle JP, Broglio KR, Thompson TJ, Geiss LS, Narayan KM: A dynamic Markov model for forecasting diabetes prevalence in the United States through 2050. *Health Care Manag Sci* 6:155–164, 2003
2. Boyle JP, Honeycutt AA, Narayan KM, Hoerger TJ, Geiss LS, Chen H, Thompson TJ: Projection of diabetes burden through 2050: impact of changing demography and disease prevalence in the U.S. *Diabetes Care* 24:1936–1940, 2001
3. Geiss LS, Pan L, Cadwell B, Gregg EW, Benjamin SM, Engelgau MM: Changes in incidence of diabetes in U.S. adults, 1997–2003. *Am J Prev Med* 30:371–377, 2006
4. Tierney EF, Geiss LS, Engelgau MM, Thompson TJ, Schaubert D, Shireley LA, Vukelic PJ, McDonough SL: Population-based estimates of mortality associated with diabetes: use of a death certificate check box in North Dakota. *Am J Public*

- Health 91:84–92, 2001
5. Tierney EF, Cadwell BL, Engelgau MM, Shireley L, Parsons SL, Moum K, Geiss LS: Declining mortality rate among people with diabetes in North Dakota, 1997–2002. *Diabetes Care* 27:2723–2725, 2004
 6. National Center for Health Statistics: 1990 National Health Interview Survey [database on CD-ROM]. CD-ROM series 10, no. 4. SETS version 1.21. Washington, DC, U.S. Govt. Printing Office, 1993
 7. Botman SL, Moore TF, Moriarity CL, Parsons VL: Design and estimation for the National Health Interview Survey, 1995–2004. *Vital Health Stat* 2:1–31, 2000
 8. Blackwell DL, Tonthat L: Summary health statistics for U.S. children: National Health Interview Survey, 1998. *Vital Health Stat* 10:1–46, 2002
 9. National Center for Health Statistics [homepage on the Internet]. Available at <http://www.cdc.gov/nchs/nhis.htm>. Accessed 12 July 2006
 10. Gelman A, Carlin JB, Stern HS, Rubin DB: *Bayesian Data Analysis*. 2nd ed. Boca Raton, FL, Chapman & Hall, 2004
 11. Census Bureau: *Component Assumptions of the Resident Population by Age, Sex, Race/Ethnicity, and Hispanic Origin: Lowest, Middle, and Highest Series, 1999 to 2100*. Washington, DC, U.S. Census Bureau, 2000
 12. Narayan KM, Boyle JP, Thompson TJ, Sorensen SE, Williamson DF: Lifetime risk of diabetes mellitus in the United States. *JAMA* 290:1884–1890, 2003
 13. Leibson CL, O'Brien PC, Atkinson E, Palumbo PJ, Melton III LJ: Relative contributions of incidence and survival to increasing prevalence of adult-onset diabetes mellitus: a population-based study. *Am J Epidemiol* 146:12–22, 1997
 14. Burke JP, Williams K, Gaskill SP, Hazuda HP, Haffner SM, Stern MP: Rapid rise in the incidence of type 2 diabetes from 1987 to 1997: results from the San Antonio Heart Study. *Arch Intern Med* 159:1450–1456, 1999
 15. Saaddine JB, Cadwell BL, Engelgau MM, Gregg EW, Engelgau MM, Vinicor F, Imperatore G, Narayan KM: Improvements in diabetes processes of care and intermediate outcomes: United States, 1988–2002. *Ann Int Med* 144:465–474, 2006
 16. Burrows NR, Wang J, Geiss LS, Narayan KM, Engelgau MM: Incidence of end-stage renal disease among persons with diabetes: United States, 1990–2002. *MMWR Morb Mortal Wkly Rep* 54:1097–1100, 2005
 17. Geiss L, Engelgau M, Pogach L, Acton K, Fleming B, Roman S, Han L, Wang J, Vinicor F: A national progress report on diabetes: successes and challenges. *Diabetes Technol Ther* 7:198–203, 2005
 18. Flegal KM, Carroll MD, Ogden CL, Johnson CL: Prevalence and trends in obesity among US adults, 1999–2000. *JAMA* 288:1723–1727, 2002
 19. O'Connor PJ, Rush WA, Pronk NP, Cherney LM: Identifying diabetes mellitus or heart disease among health maintenance organization members: sensitivity, specificity, predictive value, and cost of survey and database methods. *Am J Manag Care* 4:335–342, 1998
 20. Harris MI: Summary. In *Diabetes in America*. 2nd ed. Washington, DC, Govt. Printing Office, 1995, p. 1–14 (NIH publ. no. 95-1468)
 21. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, Nathan DM, the Diabetes Prevention Program Research Group: Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med* 346: 393–403, 2002